

Johnson



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON, D.C. 20546

REPLY TO  
ATTN OF:

GP

(NASA-Case-MS-C-14339-1) INSULATED  
ELECTROCARDIOGRAPHIC ELECTRODES Patent  
(NASA) 8 p

CSCS 06B

N75-24716

Unclas  
00/05 22488

TO: KSI/Scientific & Technical Information Division  
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General  
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.

: 3,882,846

Government or  
Corporate Employee

: Texas Tech Univ.  
Lubbock, TX

Supplementary Corporate  
Source (if applicable)

: ~~~~~

NASA Patent Case No.

: MSC-14,339-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☒

NO ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Woerner

Bonnie L. Woerner  
Enclosure



[54] **INSULATED ELECTROCARDIOGRAPHIC ELECTRODES**

[76] Inventors: **James C. Fletcher**, Administrator of the National Aeronautics and Space Administration with respect to an invention by; **Robert M. David**, Austin; **William M. Portnoy**, Lubbock, both of Tex.

[22] Filed: **Apr. 4, 1973**

[21] Appl. No.: **347,953**

[52] U.S. Cl. .... **128/2.06 E; 128/2.06 B; 128/DIG. 4**

[51] Int. Cl. .... **A61b 5/04**

[58] Field of Search ..... **128/2.06 E, 2.1 E, 2.06 B, 128/DIG. 4, 418, 404, 405**

[56] **References Cited****UNITED STATES PATENTS**

3,500,823	3/1970	Richardson et al. ....	128/2.06 E
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Wise et al., "Thin Films of Glass and Their Application to Biomedical Sensors," Medical & Biological Eng'ng., Vol. 9, pp. 339-349, Pergamon Press, 1971.

Lagow et al., "Anodic Insulated Tantalum Oxide, ECG Electrodes," IEEE Trans. on Bio-Med. Engineering, pp. 162-164, March, 1971.

Potter et al., "Capacitive Type of Biomedical Electrode," IEEE Trans. on Bio-Med. Eng'ng., pp. 350-351, October, 1970.

*Primary Examiner*—Richard A. Gaudet

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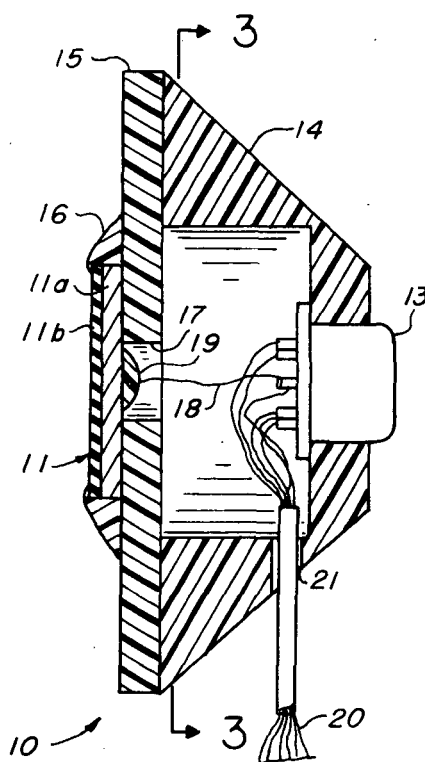
*Attorney, Agent, or Firm*—Carl O. McClenny; John R. Manning; Marvin F. Matthews

[57]

**ABSTRACT**

Disclosed is an integrated system including an insulated electrode and an impedance transformer which can be assembled in a small plastic housing and used for the acquisition of electrocardiographic data. The electrode may be employed without a paste electrolyte and may be attached to the body for extended usage without producing skin reaction. The electrode comprises a thin layer of a suitable non-toxic dielectric material preferably deposited by radio frequency sputtering onto a conductive substrate. The impedance transformer preferably comprises an operational amplifier having an FET input stage connected in the unity gain configuration which provides a very low lower cut-off frequency, a high input impedance with a very small input bias current, a low output impedance, and a high signal-to-noise ratio. The electrode may be connected directly into a standard monitoring system normally employed with conventional paste-type electrodes.

**5 Claims, 7 Drawing Figures**



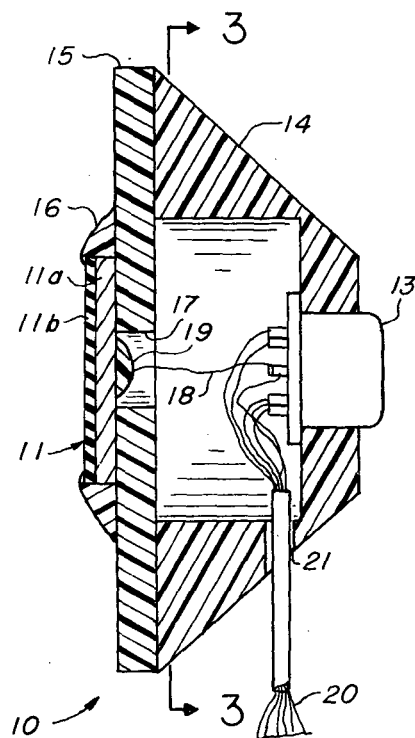


FIG. 1

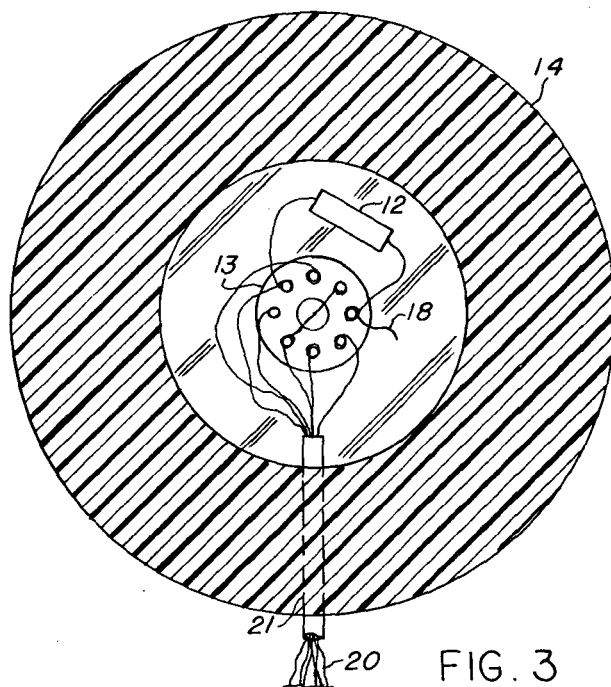


FIG. 3

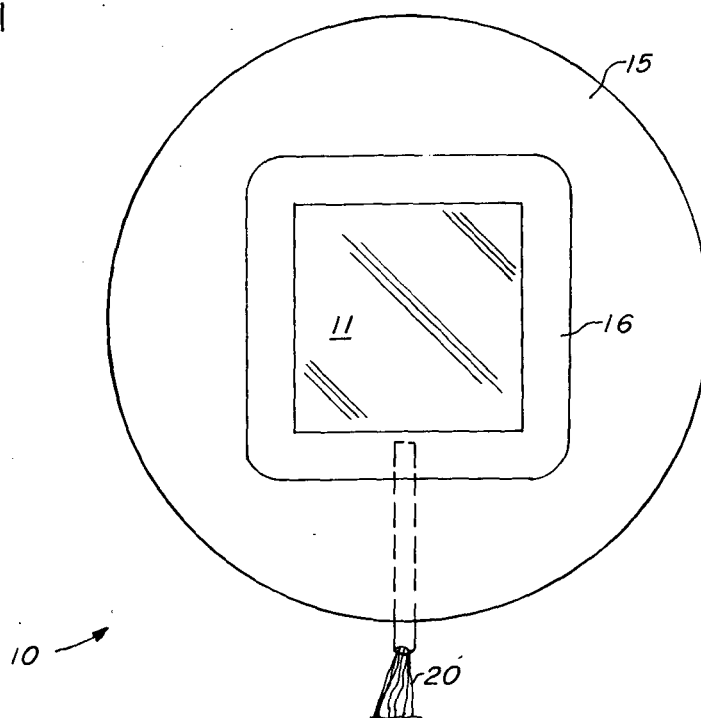
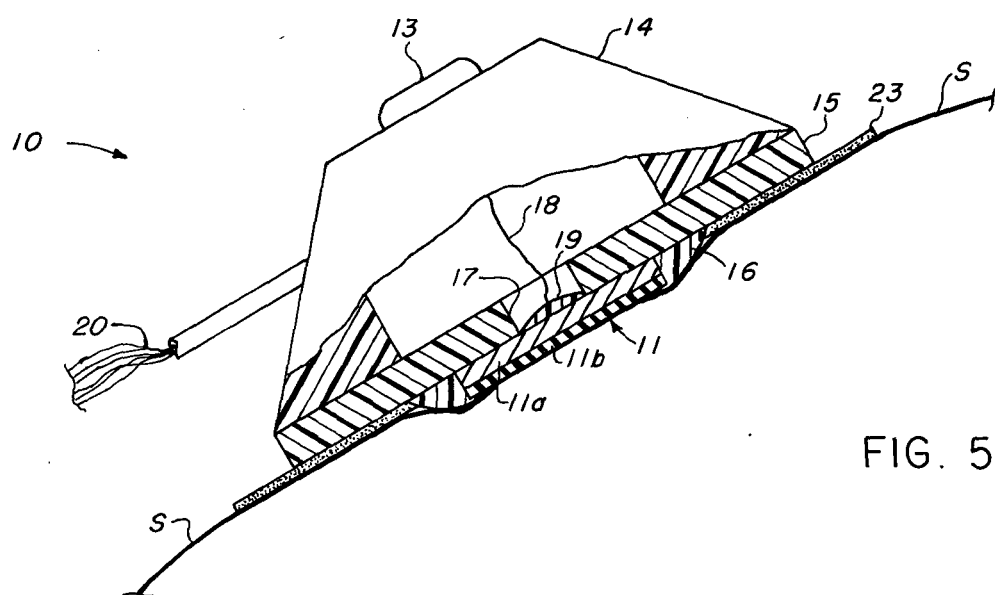
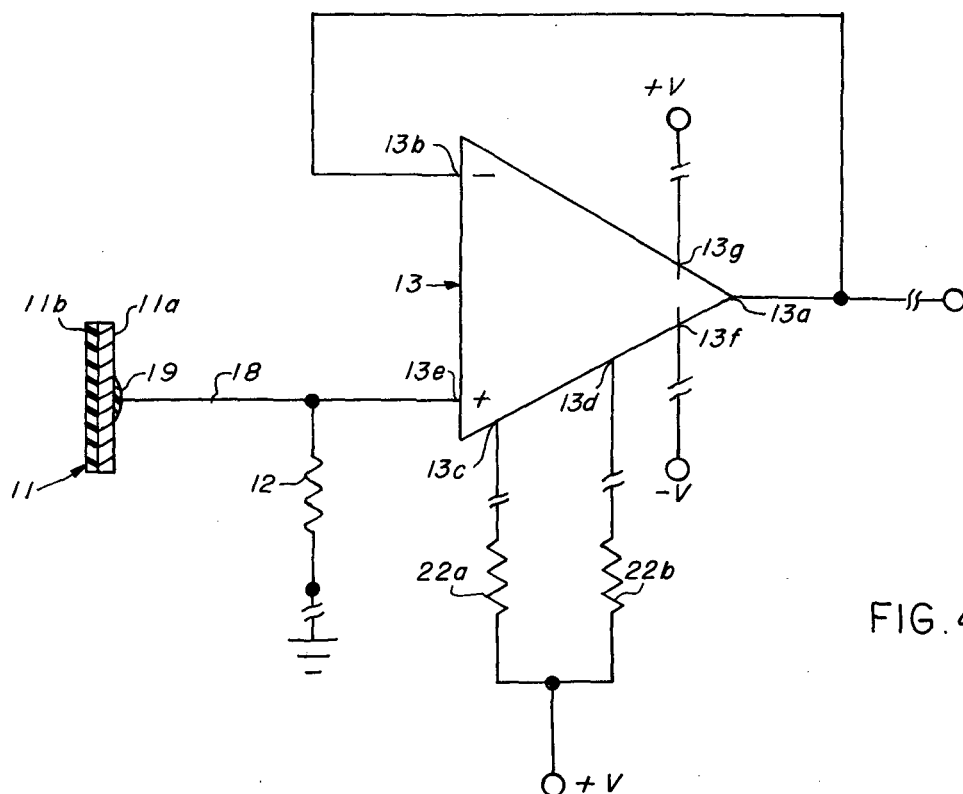


FIG. 2



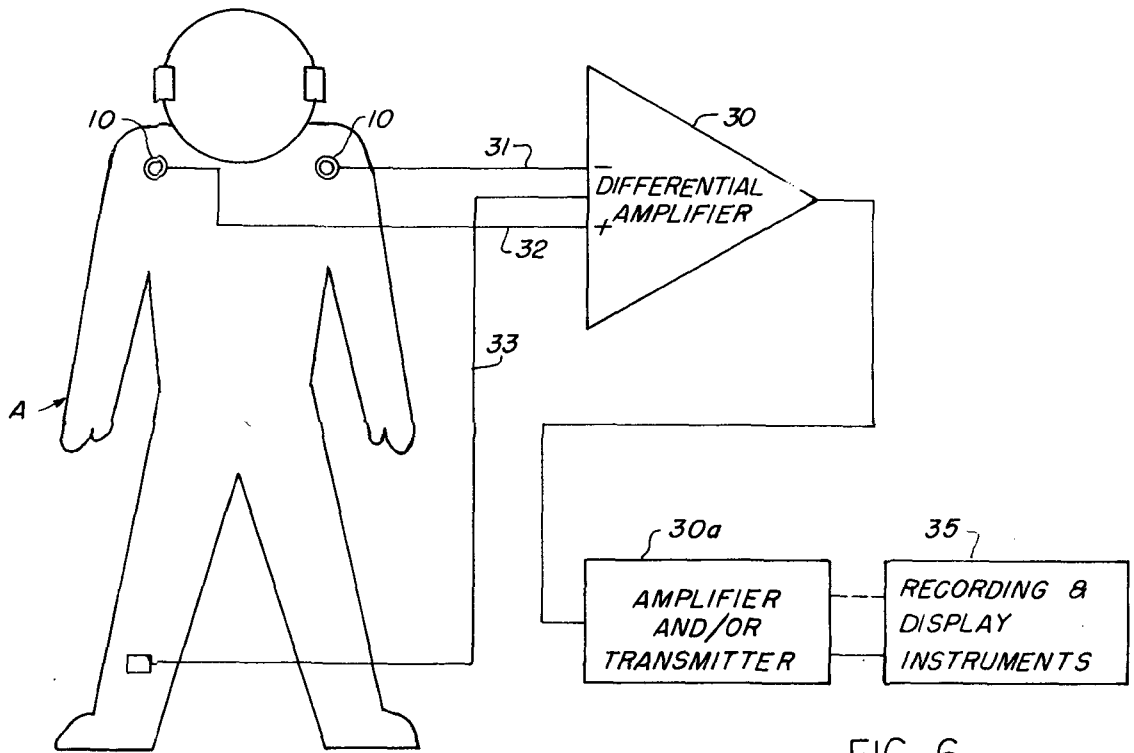


FIG. 6

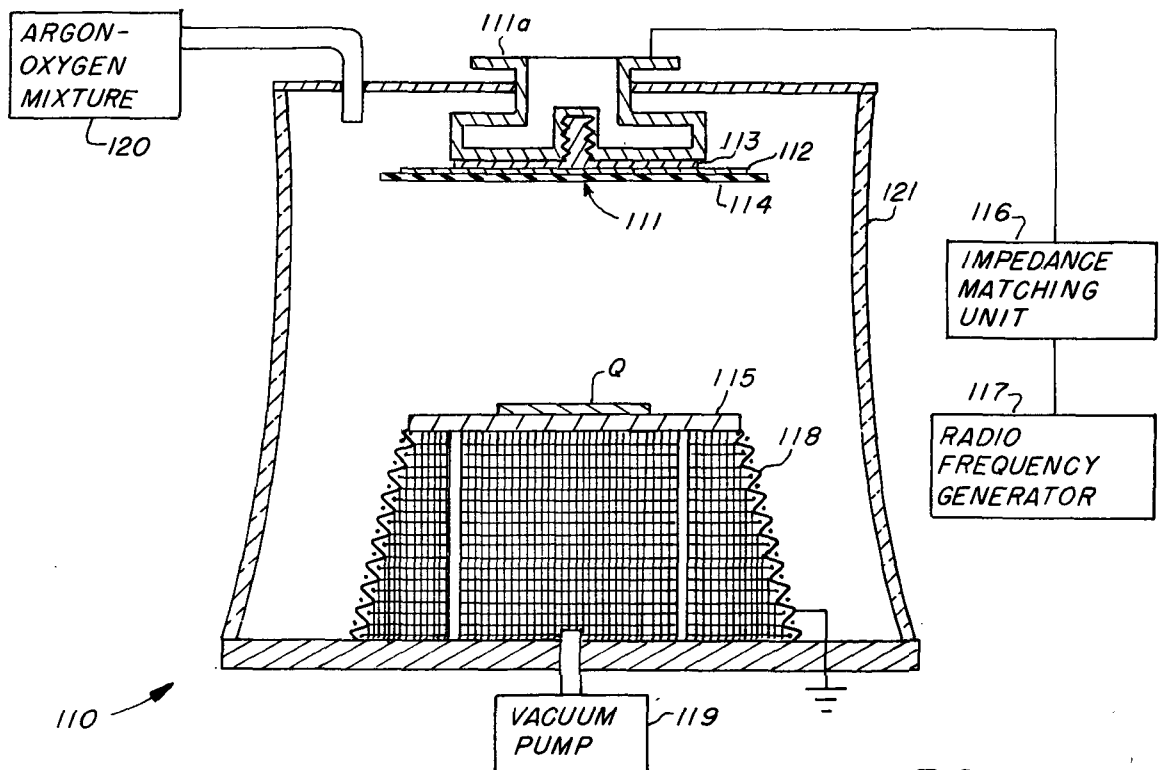


FIG. 7

## INSULATED ELECTROCARDIOGRAPHIC ELECTRODES

### ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 45 U.S.C. 2457).

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to electronic sensors for monitoring variable parameters. More specifically the present invention relates to an insulated, capacitively coupled electrode for sensing bioelectric potentials or signals.

#### 2. Description of the Prior Art

The electrode which has been found most generally satisfactory for the acquisition of electrocardiographic data is a conducting silver-silver chloride electrode which makes a low impedance contact with the skin through a paste electrolyte. However, conductive electrodes when used for extended periods of time, as for example by spacecraft personnel and medical patients requiring intensive care monitoring, exhibit inadequacies which limit their effectiveness. In such cases, the paste may dry resulting in a significant increase in skin-to-electrode resistance which may produce unacceptable biological waveform distortion. Bacterial and fungal growth can also take place under electrodes worn for extended periods and skin irritation often occurs when the electrolyte remains in contact with the skin for long periods of time. Another disadvantage of the conductive electrode is found in its electrical behavior in that shifts in D.C. levels at the electrode-skin interface appear as base line drift in the monitoring system.

To overcome problems encountered by using the paste-type electrodes, electrodes have been developed to be used in direct contact with the skin without the use of a paste electrolyte. Such sensors use silver electrodes or gold plated electrodes which are resistively coupled to the amplifier portion of the monitoring system. These direct contact electrodes have also had various problems since there is direct contact between the electrode and the body. Included in these problems are partial rectification or polarization of the monitored signal, chemical reactions, and extraneous noise induced by contact movement or contact pressure.

The prior art has also suggested using an insulated, capacitively coupled electrode as a sensor. In some of these electrodes, dielectric films are formed on aluminum bases by anodic oxidation and by depositing quartz, silicon monoxide, and films of organic polymers on aluminum. Thermal oxidation of silicon chips has also been employed in the formation of conventional capacitively coupled electrodes. Electrodes have also been constructed using Mylar as the dielectric material. Generally speaking, however, the quartz, silicon monoxide, and organic films are susceptible to mechanical damage, and the more mechanically sound anodic aluminum oxide films exhibit considerable electrical leakage and are difficult to manufacture.

U.S. Pat. No. 3,568,662 discloses an insulated, capacitively coupled electrode. The electrode is formed from a conductive silicon wafer with oxygen diffused into one surface for producing a silicon dioxide layer

which serves as the dielectric of the capacitor. A doping technique is employed in fabricating the electrode and formation of the dielectric requires participation of the substrate material. Because of the nature of capacitive coupling, an impedance transformer is required as a buffer between the capacitor and the monitoring device. Therefore, it is not possible to employ the patented electrode in a conventional monitoring system designed to use the paste-type electrode. Before the capacitive type electrode may be thus employed, it is necessary to modify the internal electronic circuitry of the conventional monitoring system. Doping techniques are also relatively imprecise so that production of uniform dielectric films by the method described in the previously mentioned patent is difficult to achieve. Moreover, the range of suitable non-toxic dielectric materials which can be satisfactorily applied by doping techniques is relatively limited.

Because two or more electrodes may be employed in conjunction with a differential amplifier, a constant transfer function value is required for each electrode in the system to prevent relatively large scale errors in the output. For this reason, any suitable system of manufacturing electrodes must be capable of reproducing electrodes exhibiting closely corresponding electrical characteristics.

### SUMMARY OF THE INVENTION

The present invention provides an insulated, capacitively coupled electrode which may be employed for detecting biopotential signals without using conventional paste-type electrolytes. The electrode of the present invention may be directly connected into the amplifying and display portions of existing monitoring systems which are designed to use conventional paste-type electrodes. In a preferred embodiment, compatibility with existing equipment is provided by a high performance FET operational amplifier connected in the unity gain configuration to function as an impedance transformer. By employing an impedance transformer, the high source impedance of the capacitively coupled electrode is made compatible with systems designed to be used with paste-type electrodes which have a relatively low source impedance.

The electrode portion of the present invention is formed by depositing a thin film dielectric onto a substrate by radio frequency sputtering which mechanically bonds the dielectric material to the substrate. The sputtering technique employed eliminates the requirement for participation of the substrate in the formation of the dielectric. As a result, a wide selection of substrate materials is made available, including silicon slices of the type used as substrates for epitaxial deposition, materials which can be polished to a very fine finish and a high degree of flatness before receiving the thin film dielectric layer, and materials which have sufficient strength so that they can be handled without damage to the dielectric while simultaneously providing good electrical conductivity which prevents resistive losses.

Moreover, because the dielectric thin film is formed on the substrate by radio frequency sputtering, a wide range of non-toxic materials may also be employed for the dielectric. The dielectrics which may be employed are compatible with the skin, are inexpensive, and may be easily applied uniformly to the substrate.

The insulated, capacitively coupled electrode of the present invention is employed on the unprepared skin. In operation, the skin acts as one plate of a simple capacitor while the substrate acts as the other. Because of its capacitive action, the electrode inherently functions to block D.C. drift directly at the electrode-skin interface.

From the foregoing, it may be appreciated that a primary object of the present invention is to provide an electrode capable of monitoring biopotential signals without the use of a paste electrolyte.

It is also an object of the present invention to provide a monitoring electrode of the type described which is of small size and which may be directly employed with existing systems.

A related object of the present invention is to provide a means for fabricating a monitoring electrode with a wide range of non-toxic dielectrics where the substrate does not participate in the dielectric's formation.

One of the important objects of the present invention is to provide an electrode of the type described which produces clinical quality records, may be used for extended periods on unprepared skin, and is immune from noise-producing electrode potentials.

Other features and advantages of the present invention will become more readily apparent from the following specification, the related drawings, and the claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an enlarged vertical section illustrating details in construction of the electrode of the present invention;

FIG. 2 is an enlarged front view of the electrode assembly of the present invention;

FIG. 3 is a view taken along the line 3—3 of FIG. 1;

FIG. 4 is a schematic illustration of the circuit employed with the electrode of the present invention;

FIG. 5 illustrates the electrode of the present invention applied to a subject;

FIG. 6 is a block diagram illustrating a typical application of the present invention; and

FIG. 7 is a vertical cross-sectional view of a work chamber employed in the r.f. sputtering technique employed in forming the insulated electrodes of the present invention.

#### BRIEF DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

With reference to the drawings, the insulated electrocardiogram electrode of the present invention is indicated generally at 10 in FIGS. 1, 2, and 3. The electrode 10 comprises a dielectric square 11 having a conductive substrate 11a covered on one surface by a dielectric thin film material 11b. A grounding resistor 12 illustrated in FIG. 3 and an operational amplifier 13 are electrically connected to the square 11 and are mounted in a plastic electrode housing 14. The dielectric square 11 is fastened to a plastic disc 15 with a suitable insulating resin 16. Sufficient resin 16 is used not only to assure a secure bond, but also to cover the edges of the dielectric square 11 to eliminate any possible contact between the skin and the substrate 11a, thus avoiding any skin-to-substrate shorts. An opening 17 in the center of the disc 15 allows an electrical conductor wire 18 to extend through the disc 15 so that the dielectric square 11 may be electrically connected to

the amplifier 13. The wire 18 is attached to the substrate 11a by a conductive epoxy 19 which provides electrical continuity between the dielectric square 11 and the wire. Electrical connections to the power supplies and monitoring equipment are provided by six Teflon insulated single strand wires 20 which extend through an opening 21 in the side of the housing 14.

In use, the electrode 10 is applied to a subject's skin S with double sided adhesive tape 23 as illustrated in FIG. 5. The dielectric material 11b is thus held in close contact against the skin surface to produce the capacitor configuration in which the skin acts as one plate of the capacitor and the substrate as the other. The disc 15 is preferably removable so that the dielectric square 11 may be replaced. The disc 15 can be removably secured to the housing by double-sided adhesive tape (not illustrated), or other suitable means.

FIG. 4 schematically illustrates the electrical circuitry employed in the insulated electrocardiogram electrode 10. The amplifier 13 is a high performance field effect transistor (FET) operational amplifier employing internal frequency compensation. With this type amplifier, the need for external compensating networks is unnecessary which permits the size of the electrode 10 to be reduced. The operational amplifier 13 used in the illustrated embodiment of the present invention is a  $\mu$ A740, manufactured by Fairchild Semiconductors; however, any other suitable amplifier may be used. As will be noted, the amplifier 13 is connected in the unity gain configuration with the output at 13a (pin 6) connected directly to the inverting input at 13b (pin 2). In this configuration, the amplifier 13 provides a high input impedance and a low output impedance so that it functions as an impedance transformer.

Suitable 5K ohm resistors 22a and 22b are connected from 13c (pin 1) and 13d (pin 5) of the amplifier 13 to a positive voltage supply V+. The remaining amplifier pins are the noninverting input 13e (pin 3), negative voltage supply 13f (pin 4), positive voltage supply 13g (pin 7), and ground (pin 8). The output of the electrode at 13a may be connected to the amplification, recording and display equipment employed with conventional paste-type electrodes.

In FIG. 6, a conventional configuration for placement of ECG electrodes 10 to pick-up biopotential signals is represented in a system designed to transmit signals from a spacecraft to a remote receiving station. The subject A is equipped with two electrodes and a common ground connected to the right leg. The output of each electrode 10 is applied to a differential amplifier 30 by electrical conductors 31 and 32 and the ground is connected by line 33. The output of the amplifier 30 is provided as an input to a system 30a which may contain a radio transmitter for transmitting electrocardiographic data to distant monitoring systems which include recording and display means 35. It will be appreciated of course that the output of the system 30a may also be directly connected to the recording and display instruments 35 which may include strip chart recorders or oscilloscopes or other conventional equipment.

FIG. 7 illustrates a work chamber 110 employed for sputtering of the dielectric material onto a substrate square Q. The basic system used in applying the dielectric to the square Q was an R. D. Mathis SP 310A r.f. sputtering module and generator which includes a 1 kW system having a modified target mount assembly

and a glow shorting skirt to produce uniform thin films. The chamber 110 includes a target mount assembly 111 formed by a large disc 112 of aluminum secured by bolts (not illustrated) and conductive epoxy adhesive to a second smaller disc 113, also of aluminum. The entire target mount assembly is joined to the dielectric target material 114 with moldable conductive epoxy adhesive to form one unit which is screwed into a water cooled, copper cathode 111a. The cathode 111a is electrically connected through an impedance matching unit 116 to an r.f. generator 117.

An adjustable height, water cooled copper substrate holder is indicated at 115. The basic sputtering unit has been modified by addition of a grounded copper screen skirt 118 mounted around the periphery of the holder 115 to prevent the glow discharge developed in the chamber from spreading and leaking through the vacuum system 119. The system 119 provides the necessary evacuation of the chamber 110 and a source of gas 120 supplies the desired atmosphere within the cham-

ber required for sputtering. The chamber 110 is formed by a tubular Pyrex body 121 sealed at its upper and lower ends.

While a variety of substrate materials Q may be employed, it has been determined that highly polished pieces of silicon are particularly suitable. In one form of the electrode, the substrates employed were slices of n-type silicon, Blanchard ground to a very high polish and degree of flatness. The slices were about 1Ω/cm in resistivity and about 0.25 mm thick. To prepare the silicon substrate for sputtering, the slices were degreased for 15 minutes in a boiling methanol-xylene (1:1) solution. The slices were then rinsed with deionized water and immersed in hot sulphuric acid for 15 minutes, rinsed again in deionized water and immersed in hot nitric acid for 15 minutes; they were then rinsed clean in deionized water. A final rinse was made in trichloroethylene after which the slices were dried in air and then placed in the sputtering chamber.

The sputtering was performed in an argon-oxygen mixture at a pressure of about 25 μmHg (except for the

silicon dioxide deposition, which was performed in argon) to prevent reduction of the oxides to their metals.

The dielectric targets 114 used in fabricating one group of electrodes had 4¾ inch diameters and were ¼ inch thick. The discs 112 had diameters of 4¾ inches and were ½ inch thick. The discs 113 had diameters of 3 inches and were ¼ inch thick. Eccobond 59C, a moldable conductive epoxy adhesive, was employed to bond the discs 112 and 114 to each other and a similar adhesive, Eccobond 56C, was employed to secure the disc 113 to the disc 112.

Four different dielectrics were examined during the development of the electrode, barium titanate, titanium dioxide, tantalum pentoxide, and silicon dioxide. Each dielectric was deposited onto the substrate with varying film thicknesses using a sputtering system having the specifications previously set forth. The capacitance was then measured and compared with the calculated capacitance. The results of this test are listed below in Table I.

TABLE I

Material	Nominal relative bulk permittivity	Film Thickness	Electrode Area	Lower Cut-Off Frequency	Capacitance per unit area	
		A	cm <sup>2</sup>	Hz	μF/cm <sup>2</sup>	μF/cm <sup>2</sup>
BaTiO <sub>3</sub>	1500	47000	0.81	0.032	0.044	0.29
		47000	0.80	0.021	0.064	0.29
		24000	0.81	0.024	0.058	0.57
		24000	0.76	0.032	0.047	0.57
		17000	0.72	0.016	0.097	0.75
TiO <sub>2</sub>	100	17000	0.76	0.014	0.11	0.75
		14500	0.80	0.016	0.086	0.060
		14500	0.81	0.018	0.079	0.060
		8800	0.80	0.012	0.17	0.10
		8800	0.79	0.013	0.11	0.10
Ta <sub>2</sub> O <sub>5</sub>	25	5900	0.72	0.010	0.16	0.15
		5900	0.63	0.013	0.14	0.15
		47000	0.80	0.11	0.013	0.0048
		47000	0.80	0.14	0.0099	0.0048
		32000	0.85	0.11	0.013	0.0068
SiO <sub>2</sub>	4	32000	0.85	0.080	0.017	0.0068
		17000	0.80	0.057	0.025	0.012
		17000	0.80	0.072	0.020	0.012
		32000	0.70	1.0	0.0013	0.0011
		20000	1.0	0.64	0.0018	0.0018
		20000	0.80	0.76	0.0019	0.0018
		4000	0.75	0.17	0.0088	0.0088
		4000	0.75	0.14	0.10	0.0088

ber required for sputtering. The chamber 110 is formed by a tubular Pyrex body 121 sealed at its upper and lower ends.

While a variety of substrate materials Q may be employed, it has been determined that highly polished pieces of silicon are particularly suitable. In one form of the electrode, the substrates employed were slices of n-type silicon, Blanchard ground to a very high polish and degree of flatness. The slices were about 1Ω/cm in resistivity and about 0.25 mm thick. To prepare the silicon substrate for sputtering, the slices were degreased for 15 minutes in a boiling methanol-xylene (1:1) solution. The slices were then rinsed with deionized water and immersed in hot sulphuric acid for 15 minutes, rinsed again in deionized water and immersed in hot nitric acid for 15 minutes; they were then rinsed clean in deionized water. A final rinse was made in trichloroethylene after which the slices were dried in air and then placed in the sputtering chamber.

The sputtering was performed in an argon-oxygen mixture at a pressure of about 25 μmHg (except for the

While the preferred form of the invention has been disclosed as employing a radio frequency sputtering technique in the fabrication of the electrode, it will be appreciated that other methods and apparatus capable of providing a uniform thin film of a desired dielectric material bonded mechanically to a desired substrate material may also be employed. Similarly, dielectric materials such as silicon carbide and silicon nitride as well as others may be employed in the electrode of the present invention. It will also be appreciated that substrate materials other than those specifically described herein may be satisfactorily employed in the present invention.

The foregoing disclosure and description of the invention is illustrative and explanatory thereof, and various changes in the size, shape, and materials as well as in the details of the illustrated construction may be made within the scope of the appended claims without departing from the spirit of the invention.

We claim:



1. An electrode for detecting bioelectric potentials comprising:

- a. housing means made of substantially non-electrically conductive material and having a flat outer surface portion;
- b. an electrically conductive substrate having a front face and a back face mounted in a fixed relationship to said outer surface portion of said housing means such that said substrate and said outer surface portion of said housing means are essentially parallel;
- c. a substantially non-electrically conductive dielectric material mechanically bonded to and completely covering said front face of said substrate by means of radio-frequency sputtering techniques and wherein said resulting substrate is mounted on said outer surface portion of said housing means such that said dielectric material will be in intimate contact with an external body when said electrode is placed thereon and said back face of said substrate is exposed to the internal environment of said housing means;
- d. electrically insulative encasing material extending continuously along and completely covering the edges of said substrate for preventing electrical current flow between said substrate and the external body;
- e. an impedance transforming means mounted within

said housing means and electrically connected to said back face of said substrate for providing said electrode with a relatively low output impedance and a relatively high input impedance whereby the impedance of said electrode may be matched with and connected directly to conventional monitoring equipment having a relatively low input impedance; and,

f. means for connecting said transforming means to the monitoring equipment.

2. An electrode as defined in claim 1 wherein said transforming means includes an operational amplifier having a field effect transistor input stage connected in a unity gain configuration.

3. An electrode as defined in claim 1 wherein said substrate material includes silicon and said dielectric is selected from the group consisting of barium titanate, titanium dioxide, tantalum pentoxide, and silicon dioxide.

4. An electrode as defined in claim 1 wherein said dielectric material and said substrate are secured to said outer surface portion of said housing means by an electrically insulating resin adhesive.

5. An electrode as defined in claim 1 wherein said outer surface portion is removably secured to said housing.

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